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INTRACELL FLUX TRAVERSES

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INTRACELL FLUX TRAVERSES

By Herbert Kouts

In order to find the thermal utilization in slightly enriched uranium, light water moderated lattices, we have been measuring the flux variation over individual lattice cells. So far measurements have been made with .750 inch diameter rods of 1.027% enrichment, and with .600 inch diameter rods of 1.3% enrichment. This memorandum includes results of the latter measurements; the former are reported on BNL log C - 6687.

In this phase of the study we have measured flux plots at water-to-fuel volume ratios of 4:1, 3:1, 2:1, 1.5:1, and 1:1. There is in addition to the clean water measurements a set which was made with various concentrations of B_2O_3 dissolved in the moderator. All these are reported here.

EXPERIMENTAL METHODS: All fluxes were measured by activation of dysprosium. The foils used are made of equal weight mixtures of dysprosium oxide and lucite; the powder mixture was pressed in a standard metallurgy press to a thickness of about 10 mils, and punched into foils of about 1/16 inch in diameter.

In each case thirteen foils were placed in a fuel rod in a crossed pattern, as shown in figure 1. Although only about ten mils of uranium separated the edge of one foil from the edge of the next, we had demonstrated to our satisfaction that there was no apparent interference between neighboring foils.

Foils in the water were placed along two lines, one between the centers of the neighboring fuel rods, and one along the median of a triangular lattice cell. The total number of points at which fluxes were measured in a single lattice varied from 19 (1:1 volume ratio) to 29 (4:1 volume ratio). A typical foil distribution in the water is shown also in figure 1.

During the earlier measurements a shortage of dysprosium made it necessary to expose foils in the fuel rod and in the water at different times. A third run was then made to normalize the two sets to each other. Of course, such a procedure multiplies errors, and it was abandoned as soon as enough dysprosium foils became available. At present, the procedure is to expose all foils simultaneously at measured heights in the lattice. Where necessary, a height correction is applied to account for different elevations of rod and water foils in the (approximately) exponentially decaying neutron flux.

Foils in the fuel rod were placed in machined holes in one end of a split rod. Foils in the water were placed in a lucite or aluminum triangle which was located by contact with three fuel rods, and which was inserted through the top tube plate.

The dysprosium foils were intercalibrated several times during the set of measurements. Such a frequent intercalibration was made necessary by occasional changes in sensitivity occuring when pieces chipped off them. In a few cases the time of change of calibration factor is not known, and some measured flux values are, as a result, poor. These show up as obviously large deviations of measured points from the smooth flux curves.

Where activities were high enough, all foils were counted to a total of at least 10,000 counts (1% mean statistical accuracy). In some cases the activities were low (notably in the boron poisoned lattices), and the statistical fluctuations are accordingly high.

RESULTS: The measured fluxes are listed in the attached tables and plotted on the attached curves. The key to the coding on the graphs is given in table 1. In every case the flux is normalized to a value of 1.000 at the center of the fuel rod for the best smooth curve.

The drawing of the best smooth curve was done subject to two conditions. First, it is not possible to place a foil precisely at the surface of the aluminum rod jacket, and therefore, the curves so drawn as to join the separate portions in the water and in the aluminum at the point which seems best (a small allowance is made for absorption in the aluminum).

Second, a glance at figure 1 shows that the two lines of measurement in the water contain one point in common. Thus the curves have to be drawn in such a way as to give the same value for the flux at these two points.

A feature of the results which is immediately apparent is that the flux dip in the fuel rod decreases steadily with decreasing water-to-metal ratio. This result can be seen from figure 2, where we have plotted water-to-metal ratio against the average flux in the rod, and the amount of flux dip from edge to center. This effect can be attributed, of course, partly to the difference in neutron temperatures in different lattices.

The same effect can be observed to some extent for a constant water-to-metal volume ratio and varying boron concentrations. Here, however, some anomalies appear. For the 1:1, 2:1, and 3:1 lattices only one poison concentration was used, and the flux dip in the rod is less for the poisoned lattice than for the clean lattice, as expected. The peak value of the neutron flux in the moderator is also less for the poisoned lattices than for the corresponding clean lattices.

In the 1.5:1 and 4:1 lattices, flux plots were made with three concentrations of boron in the water. Neither the flux dips in the rod nor the flux averages are monotonic functions of the poison concentration. Such a result seems unlikely, and it is to be investigated more thoroughly in the next set of lattices. This anomaly may be caused by the shape of the dysprosium absorption cross-section, which we discuss in the next section.

For at least one lattice (4:1 volume ratio, clean water) there appears to have been an error in the recorded relative heights of foils in the water and in the uranium. This error shows up as an apparent deviation of the 4:1 points from the smooth curves of figures 2 and 3. Unfortunately, the existence of this error was not detected in time to permit repeating the measurement.

POSSIBLE ERROR DUE TO Dy CROSS-SECTION: The choice of dysprosium as a detector was made at a time when little was known about the behavior of the cross-section in the thermal region. What data had been published indicated a fairly uniform 1/v behavior of the absorption cross-section, with apparently no strong resonances under a few volts. Later and better cross-sections show a decided departure from a 1/v behavior. There are two wide resonances of heights 350 barns and 300 barns at respectively 1.7 and 5.5 ev., and the interference between these resonances and the normal 1/v absorption causes a strong dip in the absorption cross-section from about .025 to about 1.5 ev. Thus the energy response of the detectors to the neutron flux is certainly not too close to that of the hydrogen in the moderator, or to that of the uranium. The effect of such a cross-section behavior must be to underestimate the flux where absorption is relatively strong (uranium) and to overestimate it where absorption is weak (moderator). Without any information on the shape of the neutron distribution, it is difficult to judge the effect of the energy varia-

tion of the dysprosium cross-section. We hope, however, to have more information soon on this point.

There is some evidence in the published literature that the error introduced by use of dysprosium is not large. Measurements of flux traverses in fuel rods in D_2O lattices have been made at North American Aviation[1] with indium and gold foils, and at Argonne National Laboratory[2] with indium, gold, and dysprosium. For the same lattice spacings and rod sizes, the Argonne and North American results agree; the Argonne results obtained with dysprosium agree also with those obtained with other kinds of foils.

Thus if there is any appreciable error from this source, it is not apparent from comparisons with results obtained with other detectors.

1. NAA - SR - 138 (part II)
2. ANL - 4800

TABLE 1

CODING OF INTRACELL FLUX PLOTS

Water-to-Metal Volume Ratio	Boron Content of Water (mg. B_2O_3/ml.)	Code
1:1	0	1 - 6 - 3 - 0
1:1	2.587	1 - 6 - 3 - 3
1.5:1	0	1.5 - 6 - 3 - 0
1.5:1	1.039	1.5 - 6 - 3 - 1
1.5:1	2.233	1.5 - 6 - 3 - 2
1.5:1	3.452	1.5 - 6 - 3 - 3
2:1	0	2 - 6 - 3 - 0
2:1	2.587	2 - 6 - 3 - 3
3:1	0	3 - 6 - 3 - 0
3:1	1.724	3 - 6 - 3 - 3
4:1	0	4 - 6 - 3 - 0
4:1	.500	4 - 6 - 3 - 1
4:1	.855	4 - 6 - 3 - 2
4:1	1.059	4 - 6 - 3 - 3

TABLE 2

INTRA CELL DATA

Ratio 1:1 Poison 0

Intra Rod Position	Value	
.250"	1.173	
.167	1.060	
.084	1.013	
.000	1.029	

Intra H_2O Position	Value	Line
.3779"	1.334	Diagonal
.4776	1.430	
.5779	1.388	
.6769	1.432	
.3788	1.351	Center-to-Center
.4799	1.332	

TABLE 3

INTRA CELL DATA

Ratio 1:1 Poison 2.587

Intra Rod Position	Value	
.250"	1.168	
.167	1.067	
.084	1.016	
.000	1.102	
Intra H_2O Position	**Value**	**Line**
.3779"	1.320	Diagonal
.4776	1.409	
.5779	1.405	
.6769	1.357	
.7786	1.401	
.3788"	1.279	Center-to-Center
.4791	1.295	

TABLE 4

INTRA CELL DATA

Ratio 1.5:1 Poison 0

Intra Rod Position	Value	
.250"	1.201	
.167	1.093	
.084	1.029	
.000	.998	
Intra H_2O Position	**Value**	**Line**
.3715"	1.424	Diagonal
.4375	1.503	
.5044	1.536	
.5692	1.532	
.6339	1.541	
.7000	1.543	
.7646	1.507	
.8312	1.488	
.4993	1.502	Midpoint (.7005 on diago
.3807"	1.437	Center-to-Center
.4420	1.492	
.5081	1.491	
.5775	1.390	

TABLE 5

INTRA CELL DATA

Ratio 1.5:1

Poison 1.039

Intra Rod Position	Value	
.250"	1.218	
.167	1.081	
.084	1.018	
.000	.994	

Intra H_2O Position	Value	Line
.3779"	1.463	Diagonal
.4422	1.545	
.5068	1.536	
.5734	1.568	
.6389	1.647	
.7038	1.594	
.7699	1.543	
.8355	1.584	
.3695"	1.495	Center-to-Center
.4340	1.540	
.4980	1.551	
.5635	1.457	

TABLE 6

INTRA CELL DATA

Ratio 1.5:1 Poison 2.233

Intra Rod Position	Value
.250"	1.206
.167	1.099
.084	1.030
.000	1.000

Intra H_2O Position	Value	Line
.3779"	1.359	Diagonal
.4422	1.405	
.5068	1.411	
.5734	1.433	
.6389	1.396	
.7038	1.488	
.7699	1.433	
.8355	1.432	
.3695	1.328	Center-to-Center
.4340	1.445	
.4980	1.456	
.5635	1.342	

TABLE 7

INTRA CELL DATA

Ratio 1.5:1 Poison 3.452

Intra Rod Position	Value	
.250"	1.224	
.167	1.109	
.084	1.032	
.000	1.008	

Intra H_2O Position	Value	Line
.3779"	1.387	Diagonal
.4422	1.347	
.5068	1.469	
.5734	1.565	
.6389	1.486	
.7038	1.503	
.7699	1.472	
.8355	1.514	
.3695	1.305	Center-to-Center
.4340	1.412	
.4980	1.368	
.5635	1.301	

TABLE 8

INTRA CELL DATA

Ratio 2:1 Poison 0

Intra Rod Position	Value	
.250"	1.210	
.167	1.092	
.084	1.019	
.000	1.021	
Intra H_2O Position	**Value**	**Line**
.3762"	1.466	Diagonal
.4445	1.566	
.5182	1.606	
.5897	1.689	
.6590	1.612	
.7304	1.627	
.7976	1.653	
.8680	1.630	
.3750	1.448	Center-to-Center
.4452	1.517	
.5140	1.617	
.5830	1.573	
.6550	1.531	

Remarks: Based on calibrations 4 and 6.

TABLE 9

INTRA CELL DATA

Ratio 2:1

Poison 2.587

Intra Rod Position	Value	
.250"	1.166	
.167	1.052	
.084	1.021	
.000	1.000	

Intra H_2O Position	Value	Line
.3762"	1.402	Diagonal
.4445	1.511	
.5182	1.568	
.5897	1.600	
.6590	1.637	
.7304	1.595	
.7976	1.567	
.8680	2.904	
.3750	1.348	Center-to-Center
.4452	1.552	
.5140	1.580	
.5830	1.479	
.6550	1.432	

TABLE 10

INTRA CELL DATA

Ratio 3:1 Poison 0

Intra Rod Position	Value	
.250"	1.229	
.167	1.106	
.084	1.028	
.000	.985	
Intra H_2O Position	**Value**	**Line**
.3751"	1.562	Diagonal
.4440	1.718	
.5125	1.807	
.5817	1.838	
.6539	1.878	
.7228	1.826	
.7933	1.830	
.8662	1.788	
.9341	1.802	
1.0055	1.792	
.3699	1.576	Center-to-Center
.4414	1.730	
.5120	1.809	
.5810	1.869	
.6513	1.883	
.7205	1.762	
.7905	1.605	

Remarks: Values are based on a complete intracell measurement done 5/12/53. Because of uncertainty in height difference of water and rod foils, a normalization of rod foils to water foils was run on 6/4/53. The calibration factors used are averages of calibration 4 and calibration 6.

TABLE 11

INTRA CELL DATA

Ratio 3:1 Poison 1.724

Intra Rod Position	Value
.250"	1.215
.167	1.093
.084	1.023
.000	.993

Intra H_2O Position	Value	Line
.3751"	1.441	Diagonal
.4440	1.591	
.5125	1.700	
.5817	1.752	
.6539	1.742	
.7228	1.748	
.7933	1.718	
.8662	1.662	
.9341	1.745	
1.0055	1.734	
.3699	1.424	Center-to-Center
.4414	1.561	
.5120	1.579	
.5810	1.632	
.6513	1.629	
.7205	1.643	
.7905	1.433	

TABLE 12

INTRA CELL DATA

Ratio 4:1 Poison 0

Intra Rod Position	Value	
.250"	1.208	
.167	1.073	
.084	1.028	
.000	1.000	

Intra H_2O Position	Value	Line
.3801	1.802	Diagonal
.4727	2.071	
.5628	2.274	
.6531	2.348	
.7434	2.361	
.8332	2.366	
.9233	2.317	
1.0130	2.298	
1.1031	2.342	
.3897	1.887	Center-to-Center
.4792	2.066	
.5688	2.220	
.6592	2.300	
.7488	2.201	
.8389	2.071	
.9315	1.771	
	2.261	Midway (.9378 on diagonal)

TABLE 13

INTRA CELL DATA

Ratio 4:1 Poison .500

Intra Rod Position	Value
.250"	1.174
.167	1.067
.084	1.018
.000	1.034

Intra H_2O Position	Value	Line
.3718"	1.418	Diagonal
.4630	1.598	
.5522	1.710	
.6438	1.707	
.7342	1.692	
.8237	1.806	
.9144	1.679	
1.0022	1.697	
1.0942	1.721	
.3766	1.366	Center-to-Center
.4685	1.515	
.5579	1.566	
.6480	1.682	
.7384	1.601	
.8285	1.498	
.9180	1.403	

TABLE 14

INTRA CELL DATA

Ratio 4:1 Poison .855

Intra Rod Position	Value	
.250"	1.172	
.167	1.050	
.084	1.023	
.000	.985	

Intra H_2O Position	Value	Line
.3718"	1.341	Diagonal
.4630	1.425	
.5522	1.612	
.6438	1.594	
.7342	1.582	
.8237	1.523	
.9144	1.539	
1.0022	1.513	
1.0942	1.475	
.3766	1.347	Center-to-Center
.4685	1.476	
.5579	1.598	
.6480	1.657	
.7384	1.618	
.8285	1.518	
.9180	1.275	

TABLE 15

INTRA CELL DATA

Ratio 4:1 | Poison 1.059

Intra Rod P Intra Rod Position	Value	
.250"	1.192	
.167	1.054	
.084	1.009	
.000	1.002	

Intra H_2O Position	Value	Line
.3718"	1.487	Diagonal
.4630	1.702	
.5522	1.778	
.6438	1.859	
.7342	1.789	
.8237	1.876	
.9144	1.833	
1.0022	1.910	
1.0942	1.928	
.3766	1.538	Center-to-Center
.4685	1.731	
.5579	1.804	
.6480	1.865	
.7384	1.872	
.8285	1.755	
.9180	1.540	

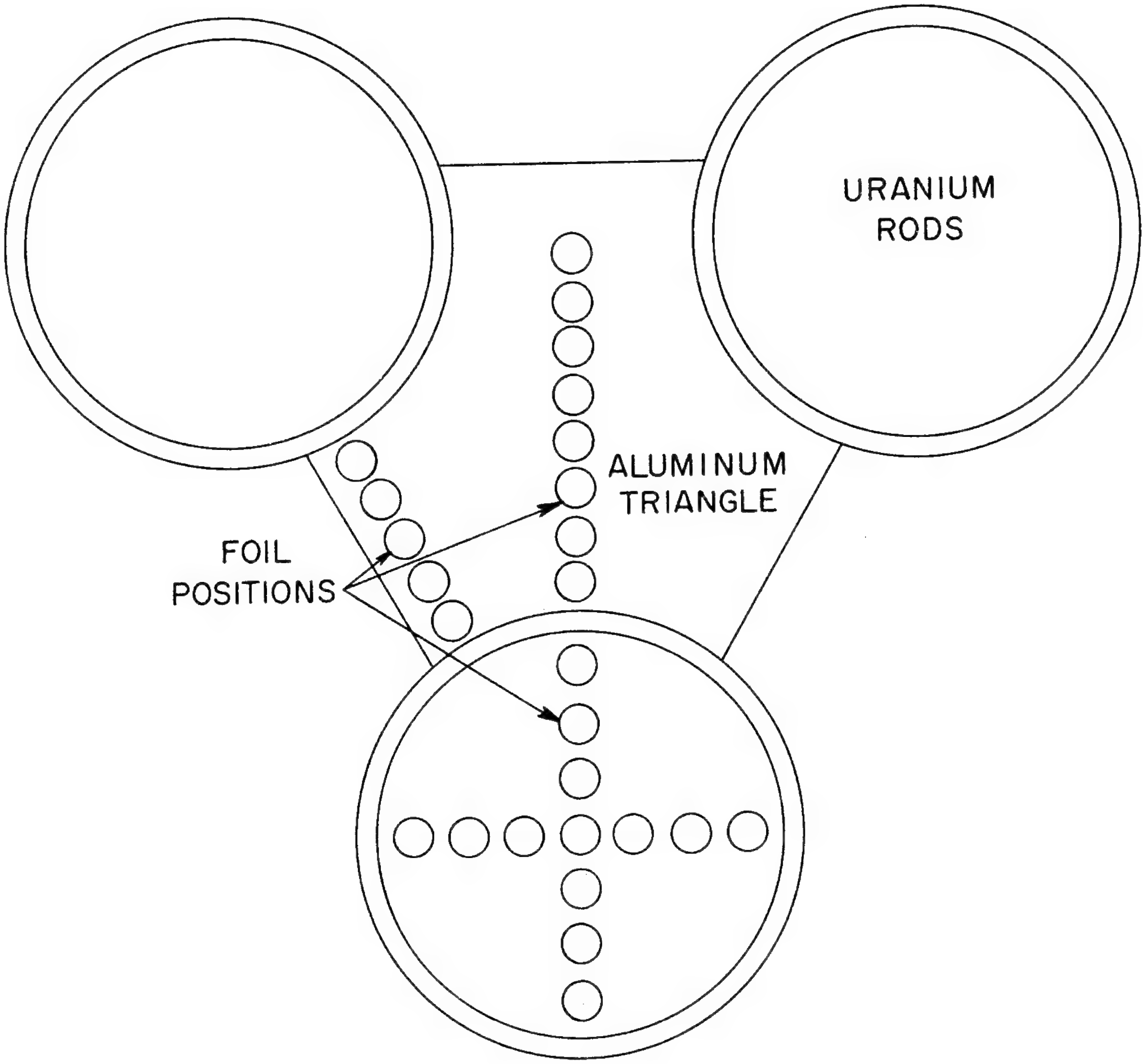


FIG. 1

FOIL POSITIONS FOR 2:1 LATTICE

SCALE 4" = 1"

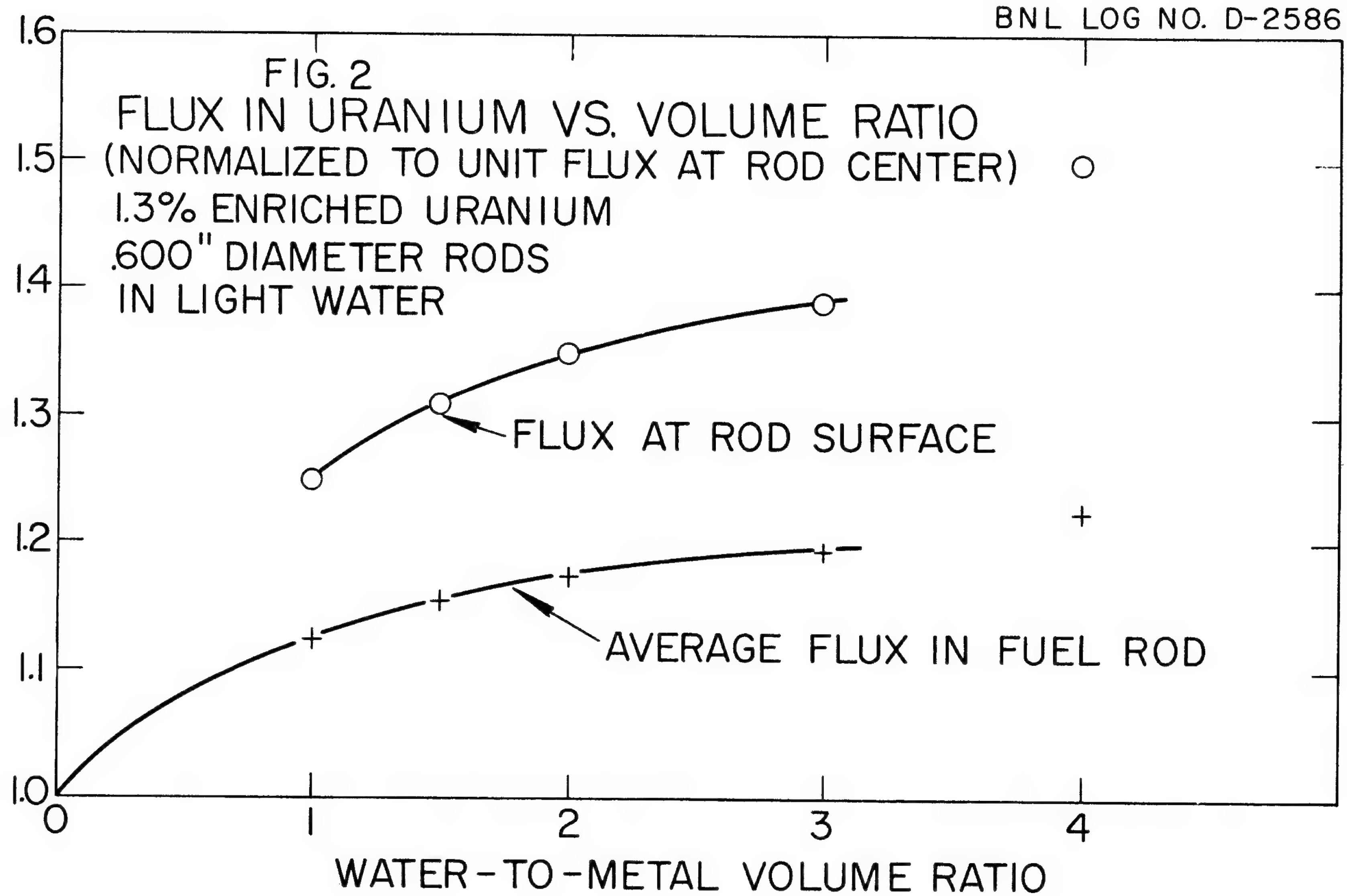


FIG. 2
FLUX IN URANIUM VS. VOLUME RATIO
(NORMALIZED TO UNIT FLUX AT ROD CENTER)
1.3% ENRICHED URANIUM
.600" DIAMETER RODS
IN LIGHT WATER

BNL LOG NO. D-2587

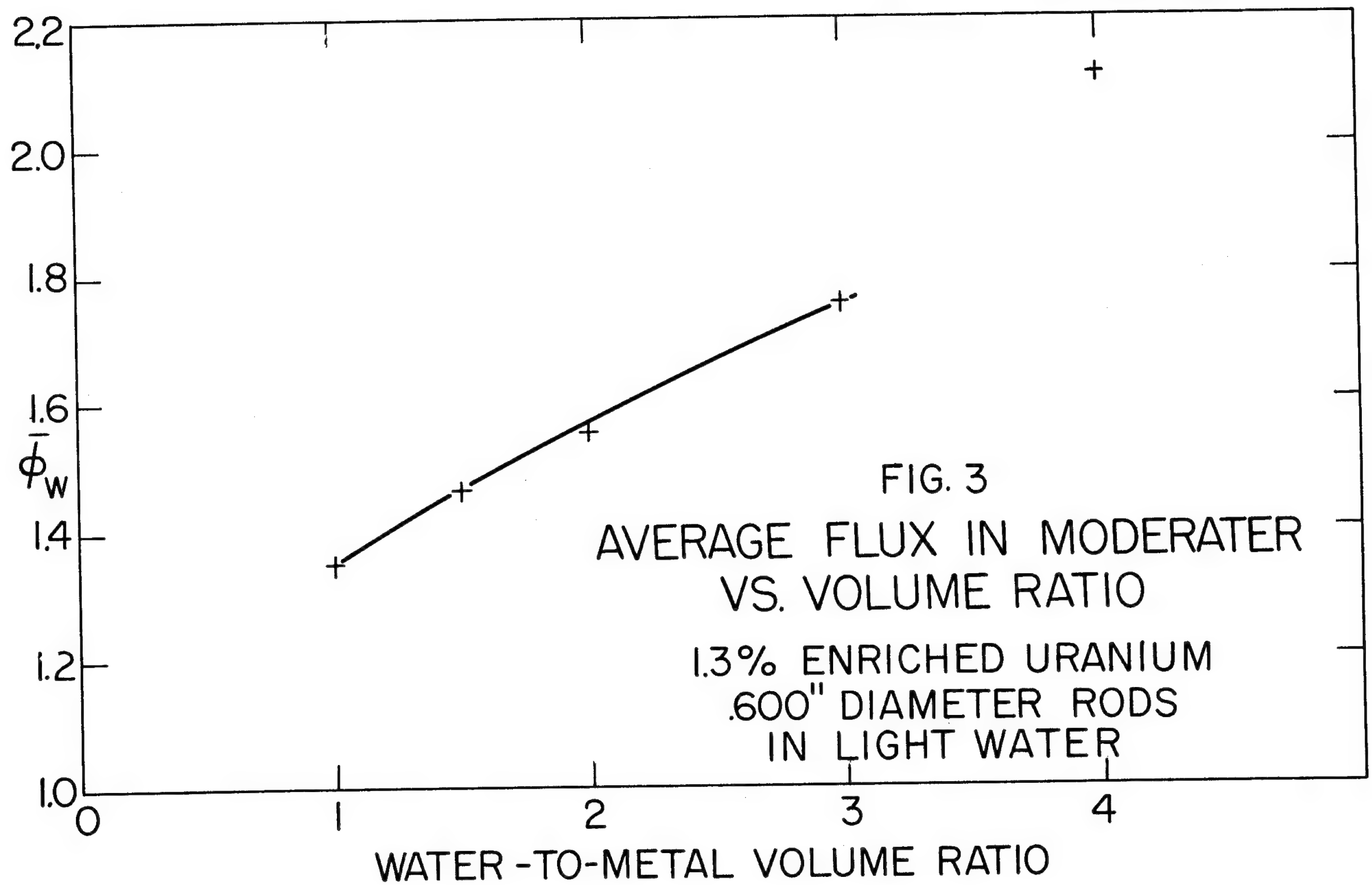
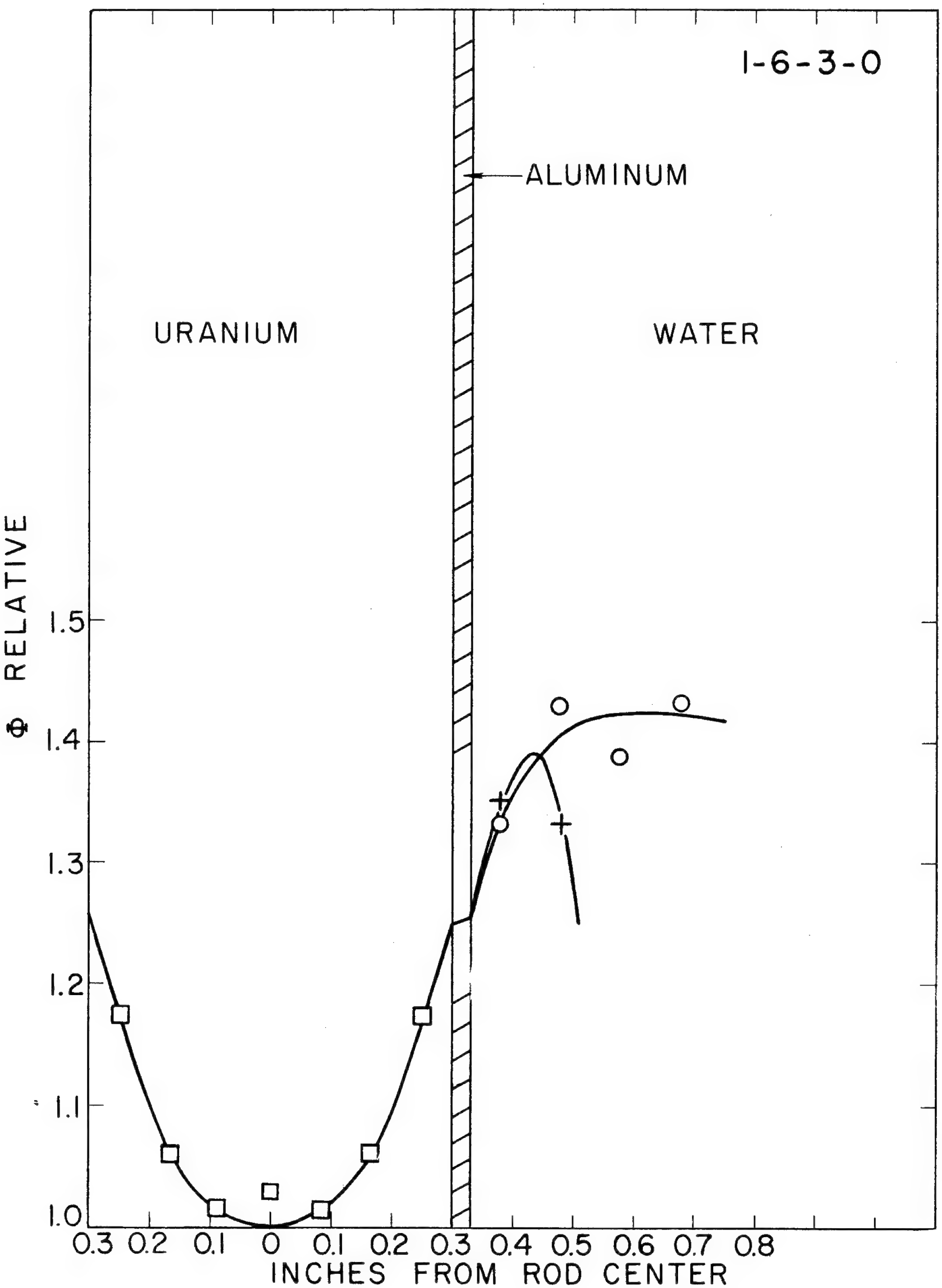


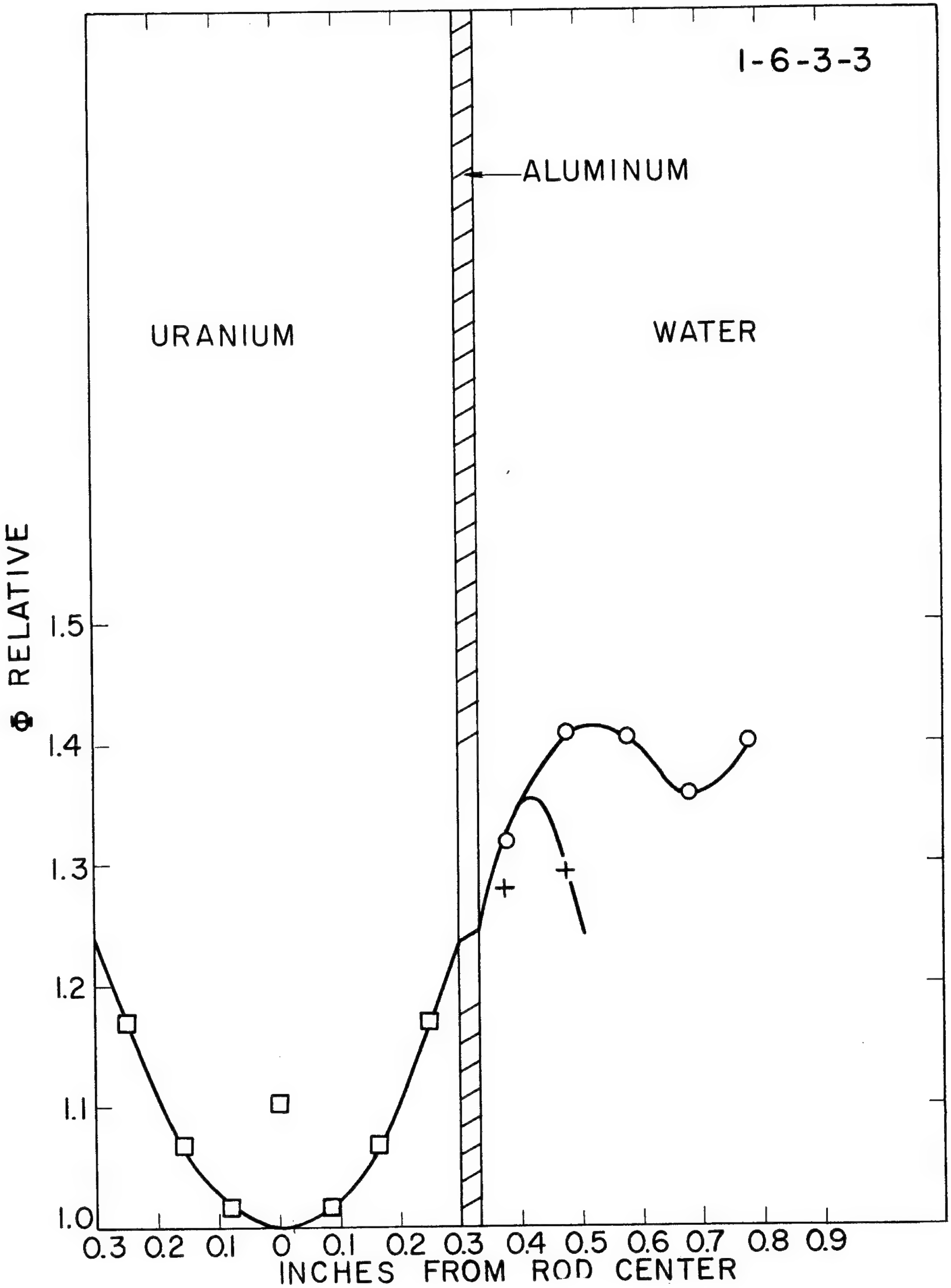
FIG. 3

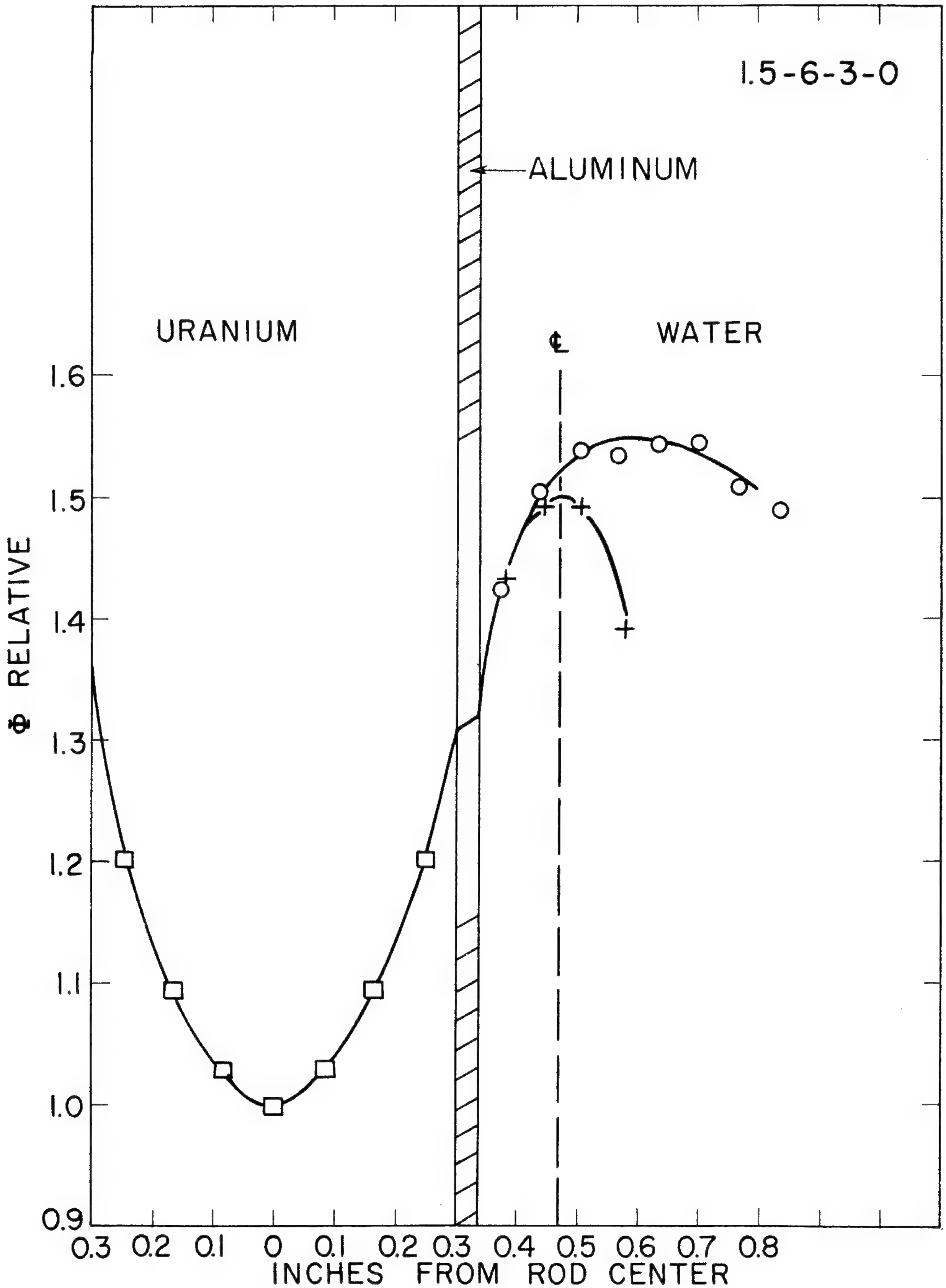
AVERAGE FLUX IN MODERATER VS. VOLUME RATIO

1.3% ENRICHED URANIUM
.600" DIAMETER RODS
IN LIGHT WATER

BNL LOG NO. D-2549




1-6-3-3
ALUMINUM
URANIUM
WATER
Φ RELATIVE
1.0
1.1
1.2
1.3
1.4
1.5
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
INCHES FROM ROD CENTER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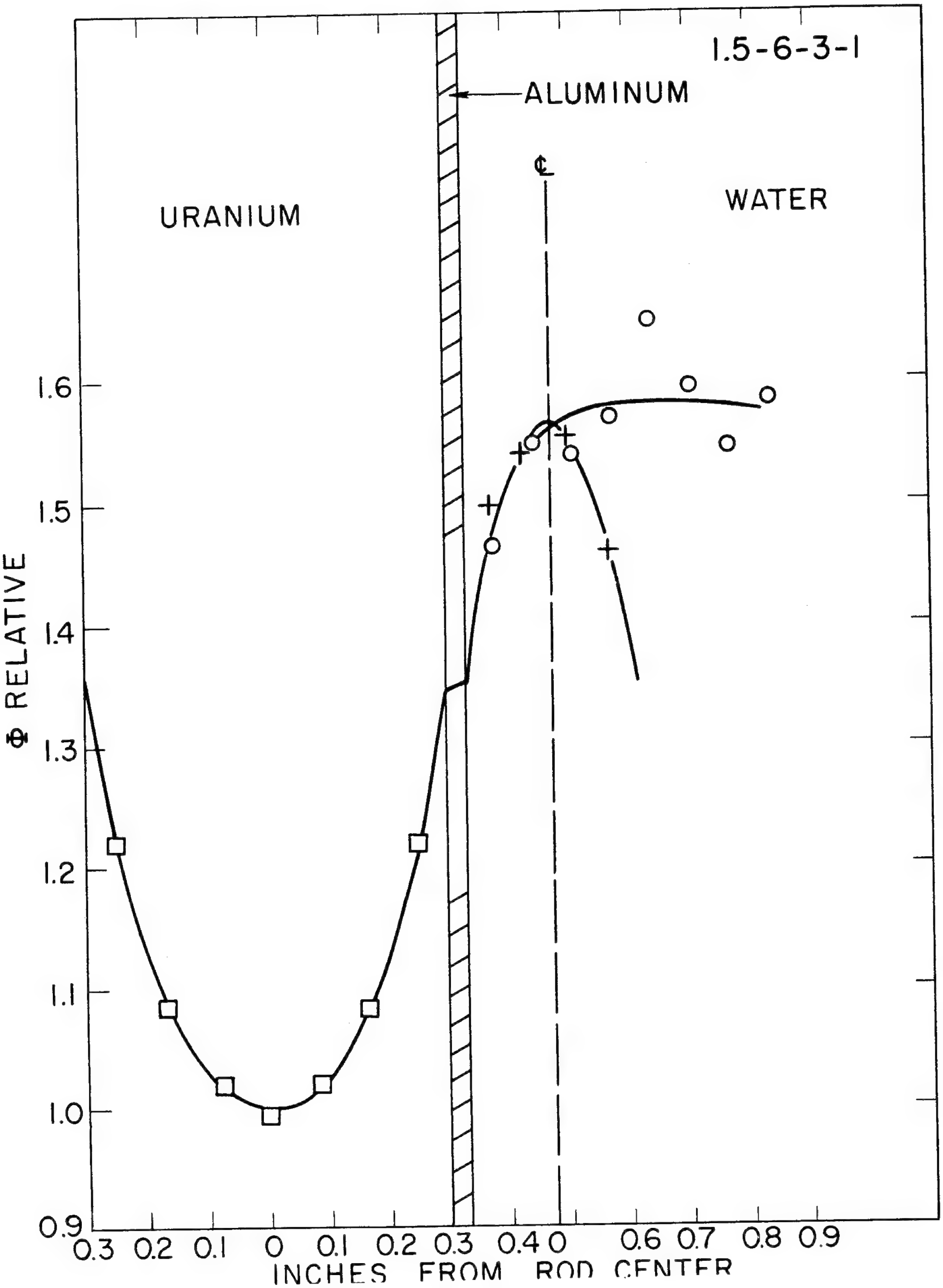
ALUMINUM
URANIUM
WATER
℄
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
Φ RELATIVE
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
INCHES FROM ROD CENTER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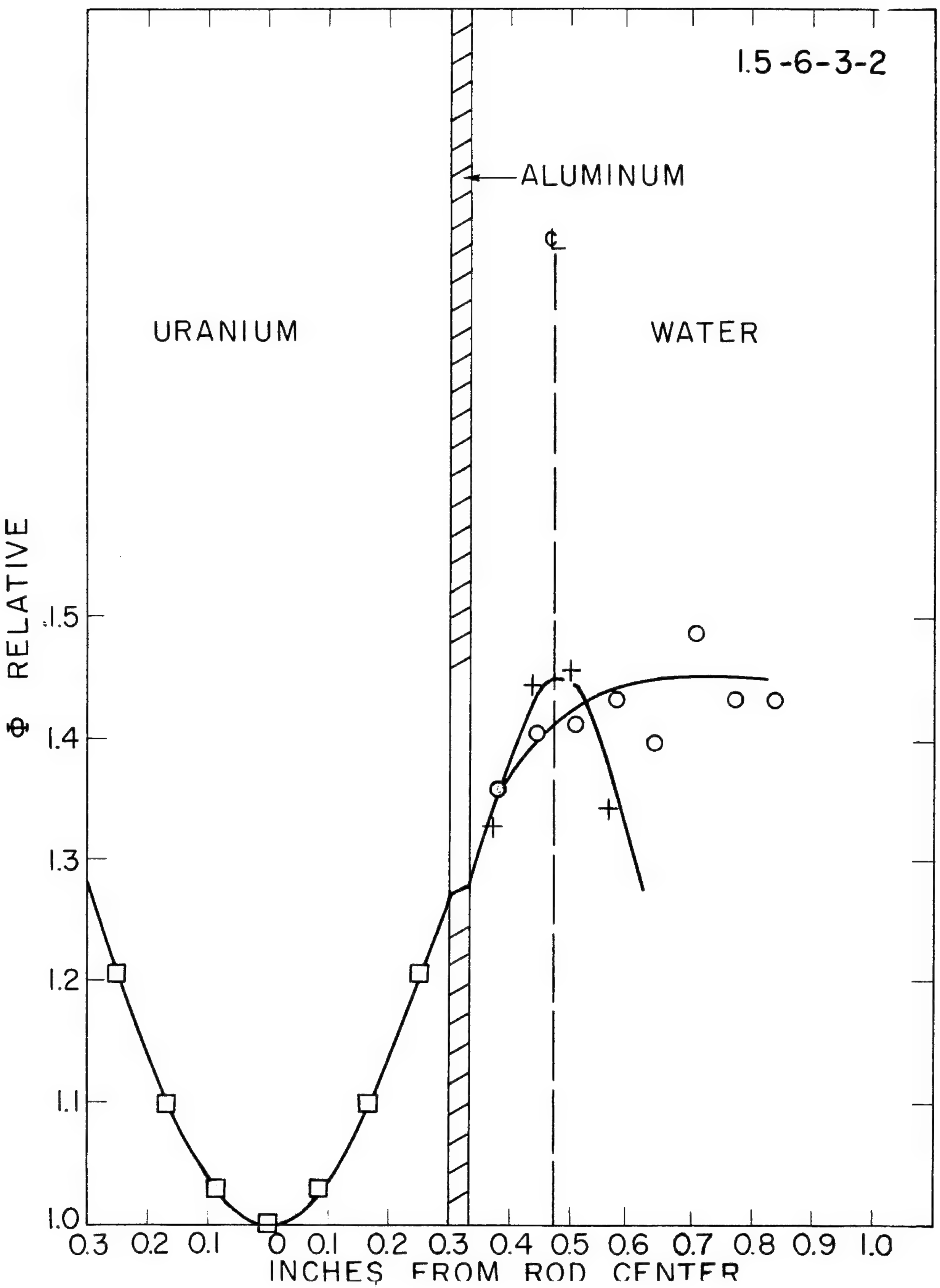
℄
URANIUM
WATER
Φ RELATIVE
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0 0.6 0.7 0.8 0.9
INCHES FROM ROD CENTER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ALUMINUM
℄
URANIUM
WATER
Φ RELATIVE
1.5
1.4
1.3
1.2
1.1
1.0
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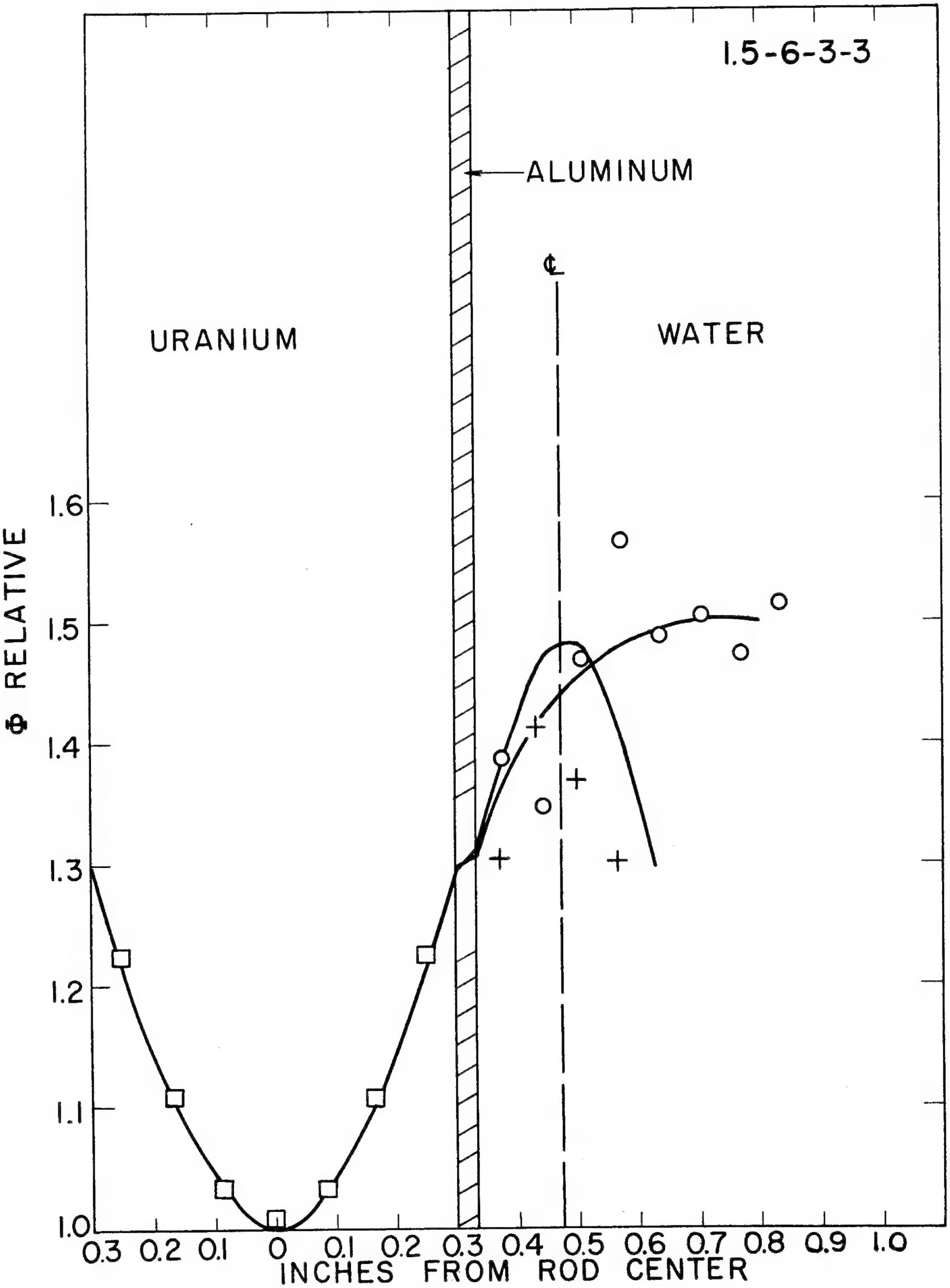
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URANIUM
WATER
℄
Φ RELATIVE
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1.1
1.2
1.3
1.4
1.5
1.6
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
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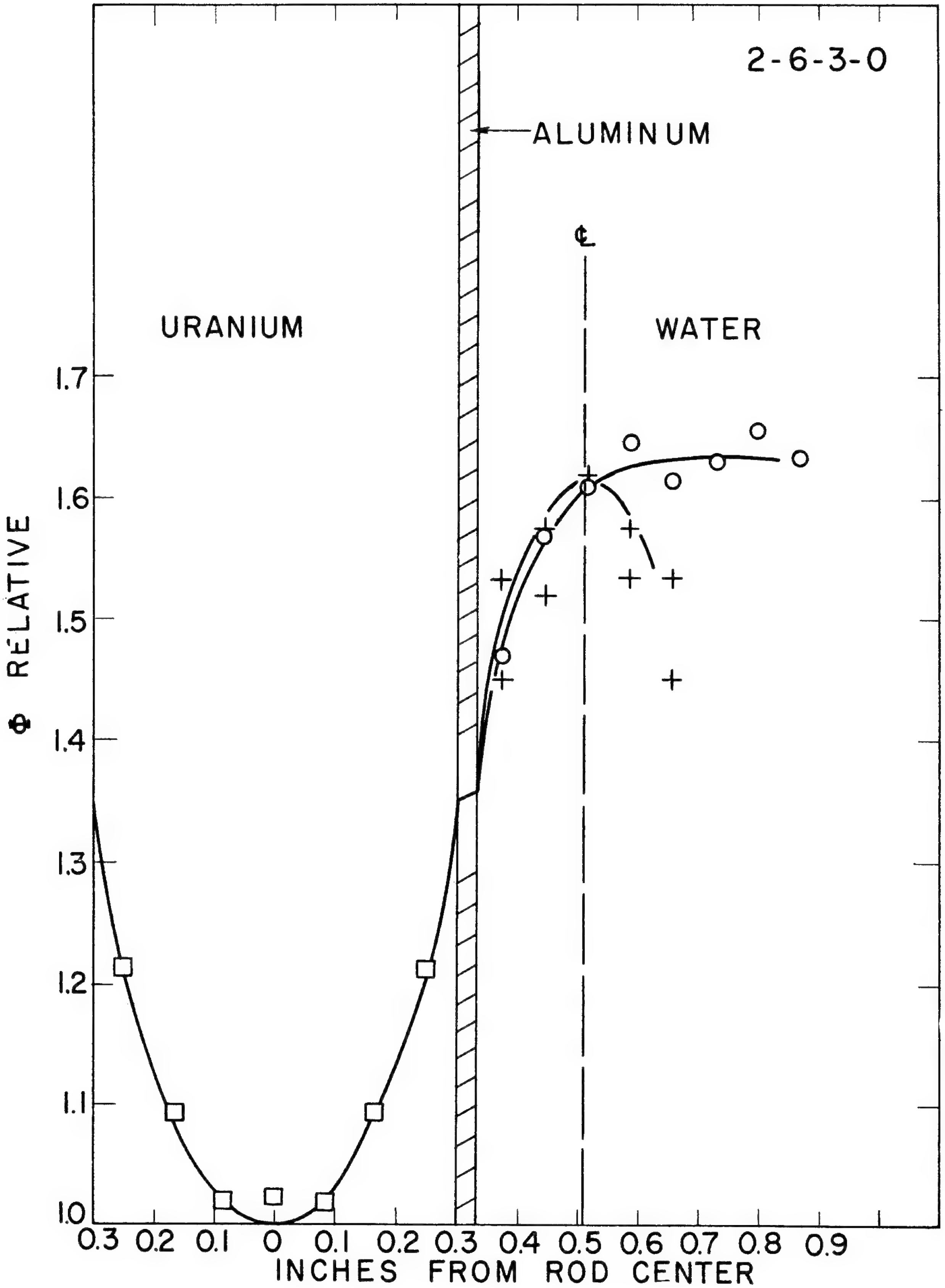
2-6-3-0
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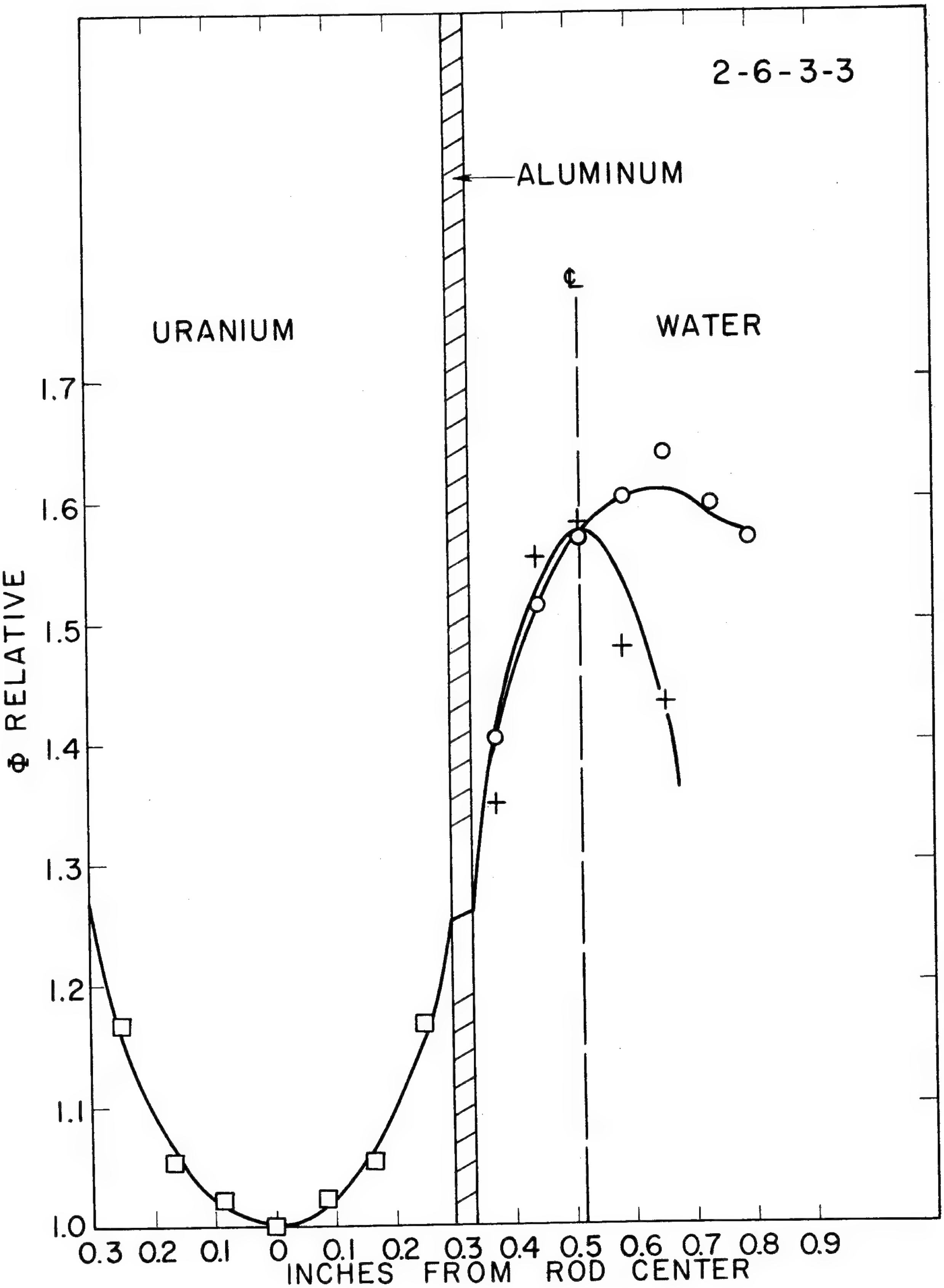
℄
URANIUM
WATER
Φ RELATIVE
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
INCHES FROM ROD CENTER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URANIUM
WATER
℄
Φ RELATIVE
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1.3
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1.5
1.6
1.7
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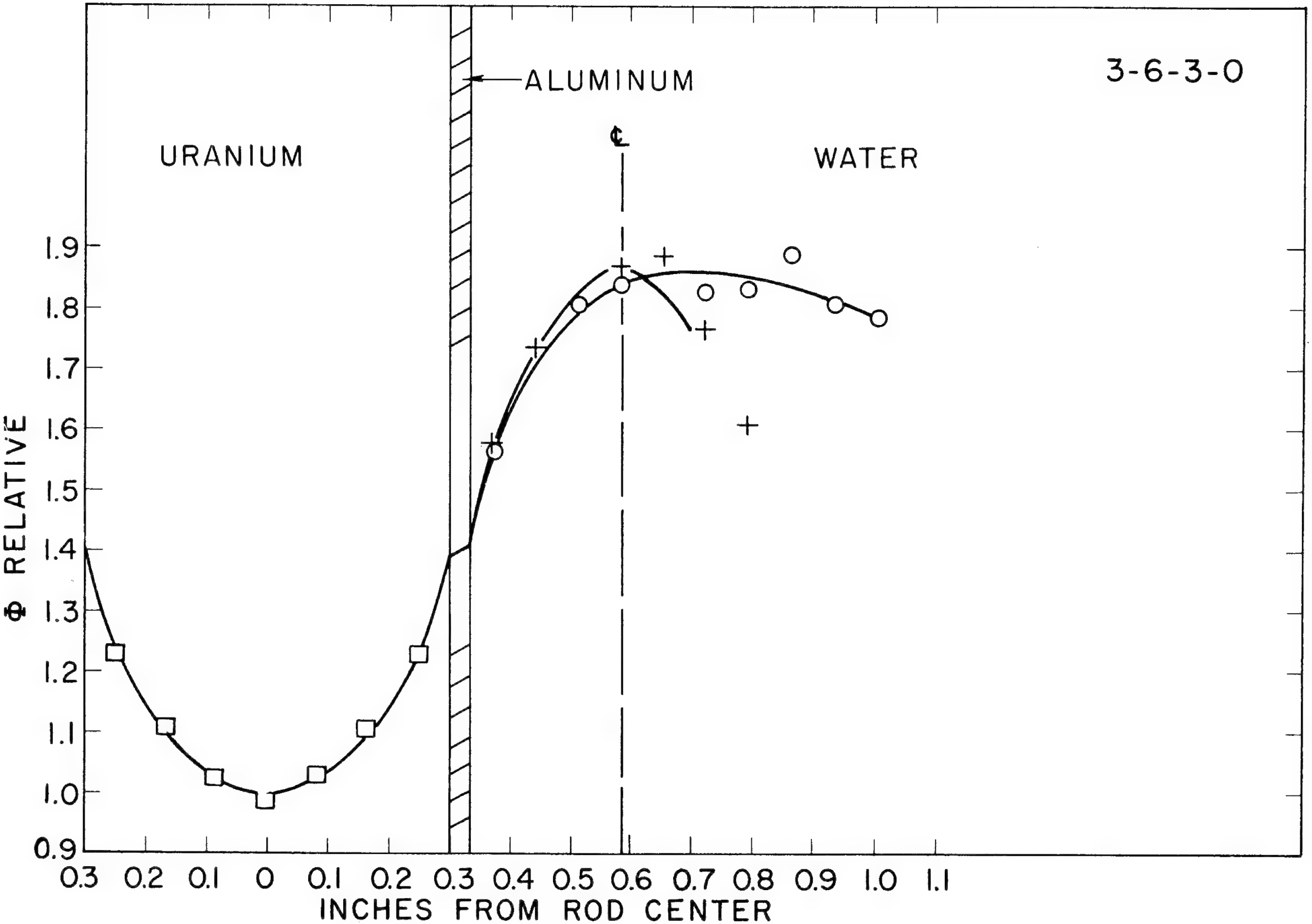
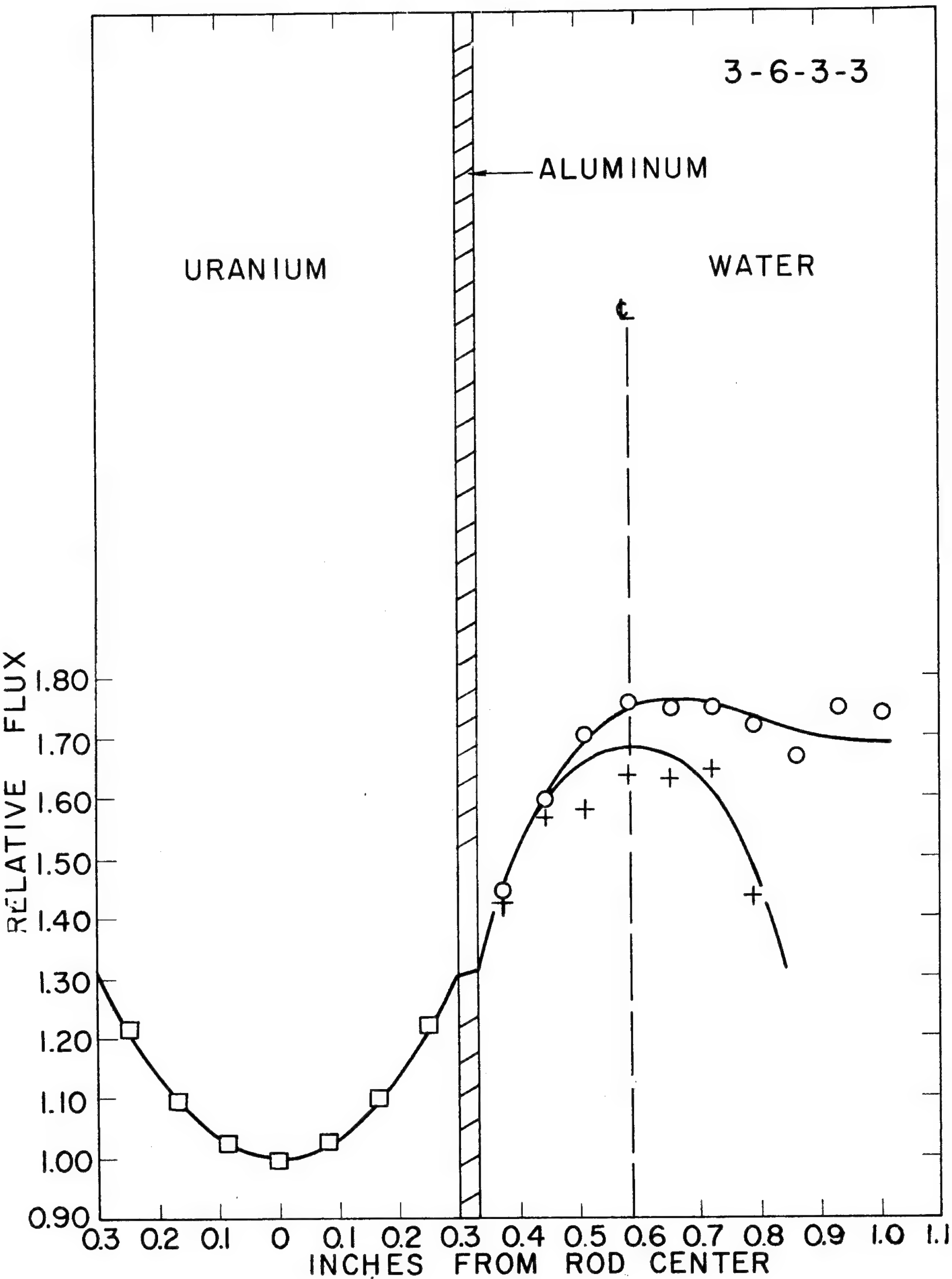
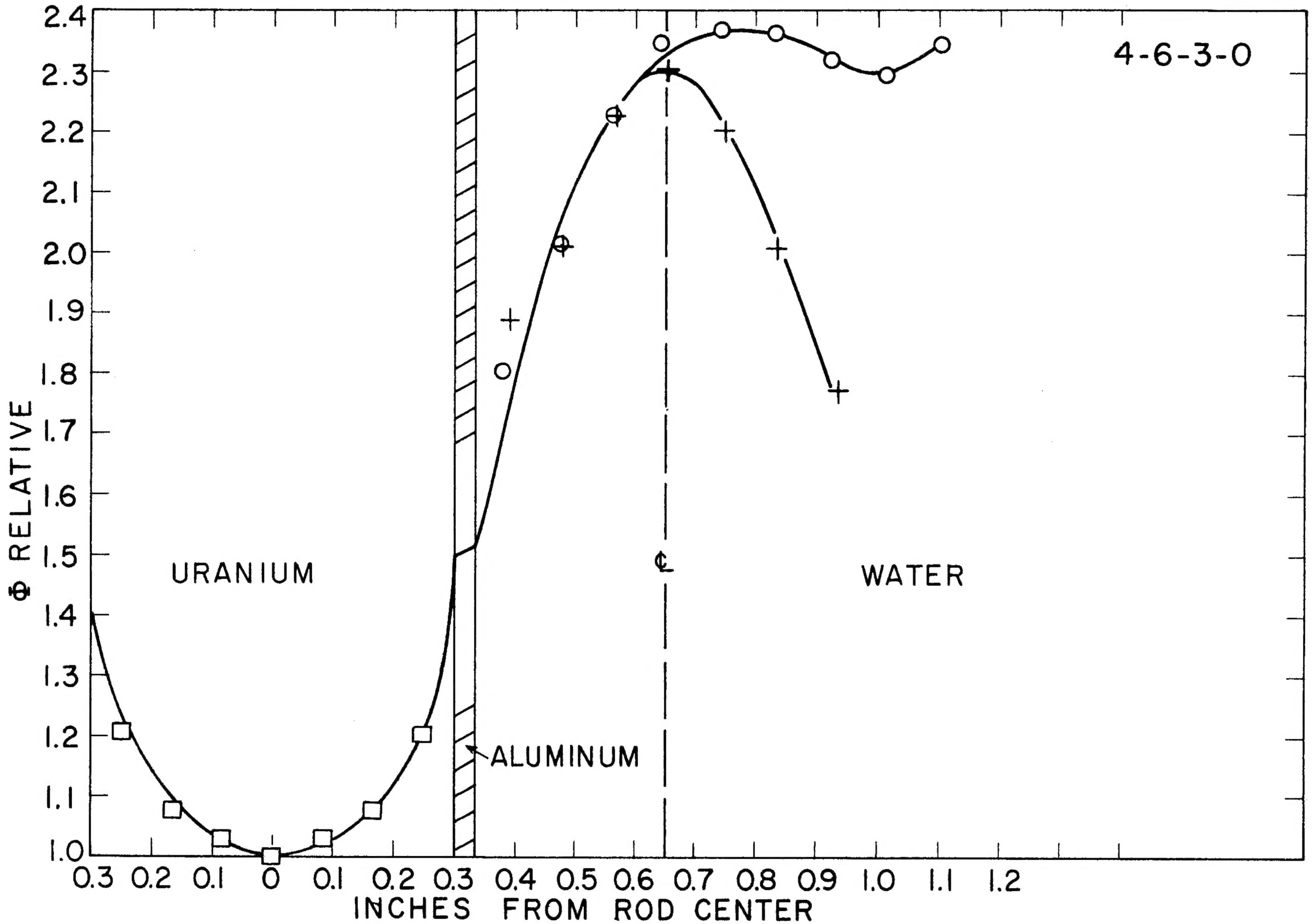
INCHES FROM ROD CENTER

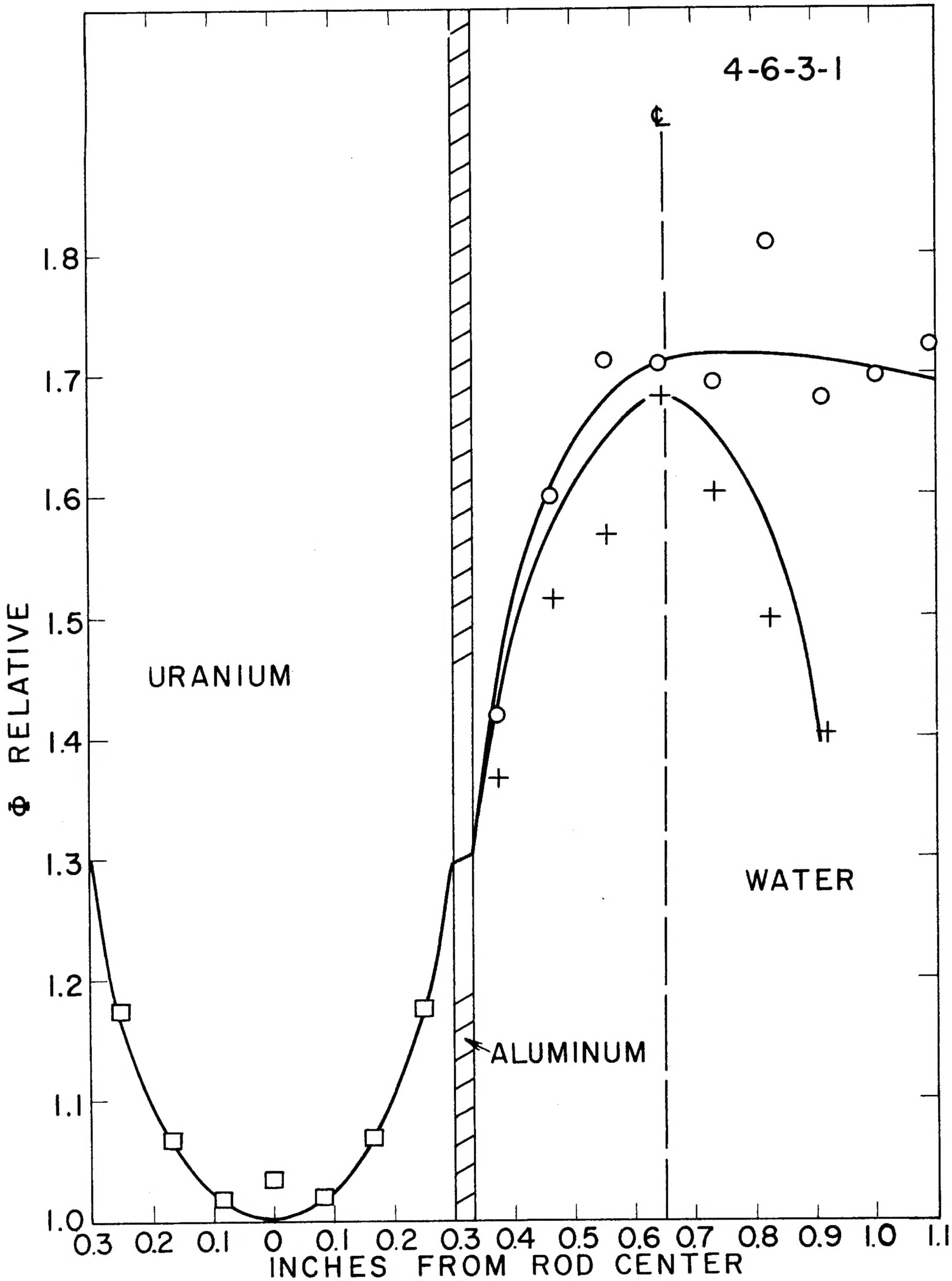
BNL LOG NO. D-2557



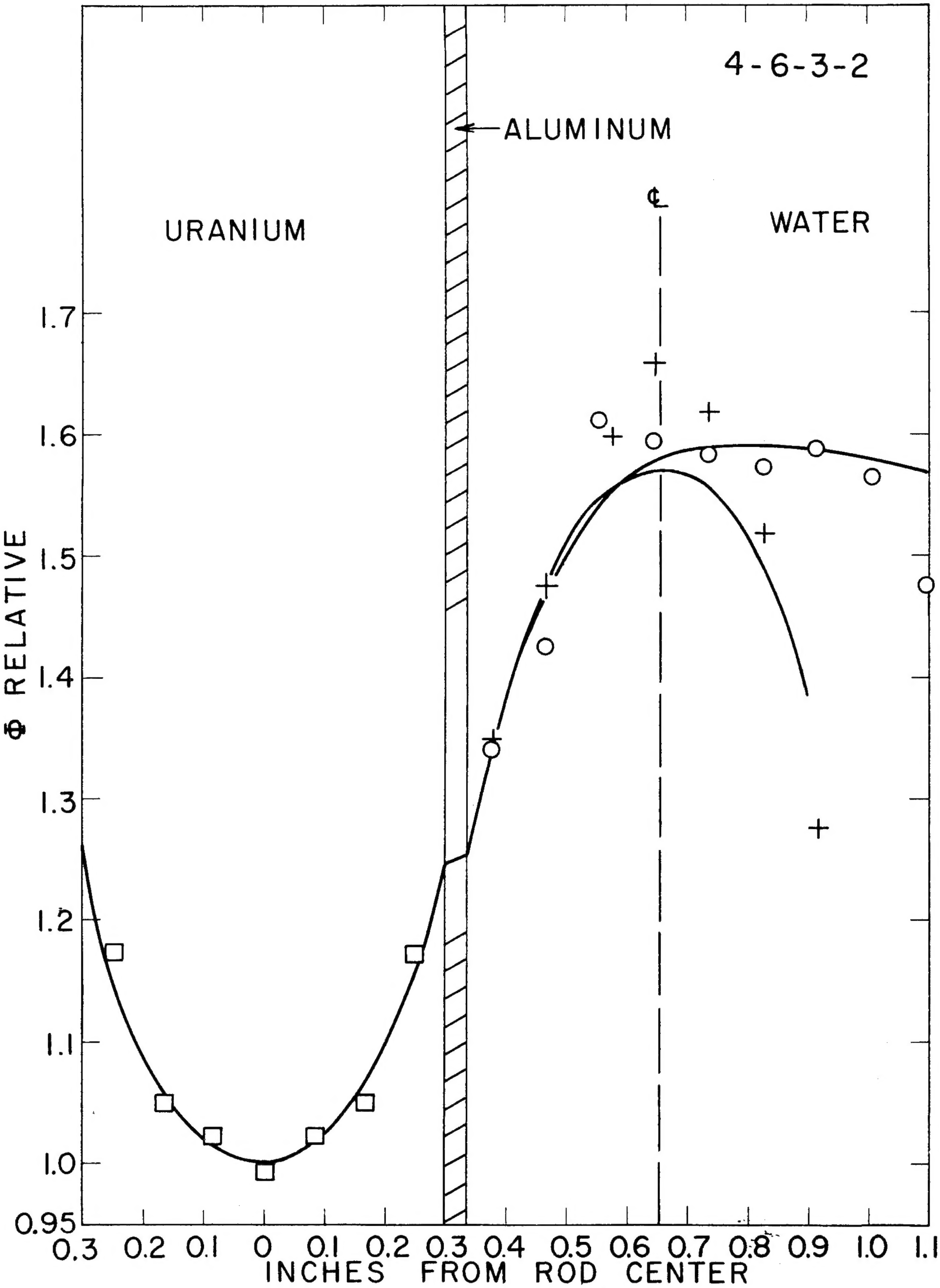

3-6-3-3
ALUMINUM
URANIUM
WATER
℄
RELATIVE FLUX
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
INCHES FROM ROD CENTER

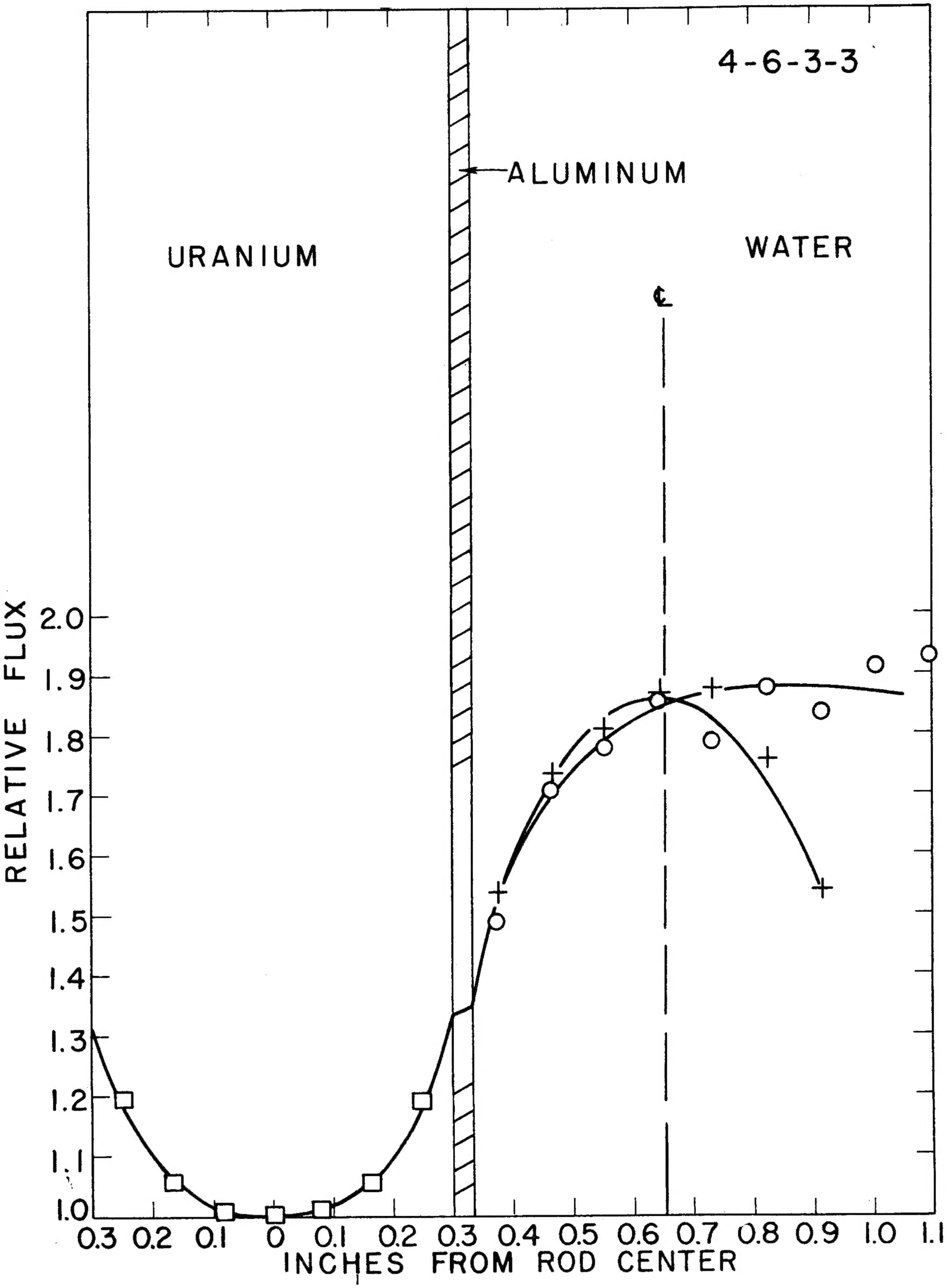

4-6-3-0
Φ RELATIVE
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
URANIUM
ALUMINUM
WATER
℄
0.3 0.2 0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
INCHES FROM ROD CENTER

BNL LOG NO. D-2560



BNL LOG NO. D-2561





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